# SPECIFICATION

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# [VARIABLE EFFECTIVE COMPRESSION RATIO USING VVT]

## Background of Invention

[0001] Field of the invention

[0002] The invention relates to achieving variable effective compression ratio in an internal combustion engine.

[0003] Background of the invention

[0004] The compression ratio of a diesel engine is defined as the ratio of the cylinder volume at bottom dead center to the cylinder volume at top dead center. The compression ratio, which is set for diesel engines in accordance with the prior art, represents a compromise between various objectives. For example, to achieve good cold-starting performance of the diesel engine, a high compression ratio is desired to create a high compression temperature to ignite the fuel and air. On the other hand, when the engine has warmed up, lower compression ratios are preferred, since they lead to lower mechanical loads and reduced combustion noise at full load.

[0005] Furthermore, tests have been able to demonstrate that at low engine torque, lower combustion temperatures, which result from high rates of cooled, recirculated exhaust gas, ensure soot-free, low-noise operation with very low $NO_X$ emissions. The increased carbon monoxide and hydrocarbon emissions which occur in this case increase the activity of the oxidation catalytic converter and therefore keep the latter thermally activated. Furthermore, soot-free, rich operation of the engine becomes possible, allowing a nitrogen oxide trap to be cleaned. A change in the compression ratio is also desirable to generate operating conditions of this type.

[0006] Not least in view of ever more stringent emissions regulations, therefore, it is desirable for diesel engines to be operated with a variable compression ratio which can be adapted to the prevailing conditions. To change the compression ratio, it is known to alter the ratio of the cylinder volume at the top dead center to the cylinder volume at the bottom dead center of the piston, for example, by changing the position of the piston relative to the crankshaft or a complete displacement of the crankshaft relative to the engine.

[0007] Furthermore, it is known from U.S. Patent 6,209,516 B1 to vary the effective compression ratio by changing the time control of the closing of the inlet valves of the diesel engine. The closing of the inlet valves (IVC: inlet valve closing) is normally just after the bottom dead center (BDC) of the piston. By delaying the IVC, the effective compression ratio is reduced. According to US 6,209,516 B1, the phase shift of a camshaft which controls the opening and closing of the inlet valves is proposed as a mechanism for delaying the IVC. However, a drawback is that the opening of the inlet valve is likewise delayed, which has an adverse effect on engine operation.

## Summary of Invention

[0008] The inventor of the present invention recognizes that a diesel engine having at least one bank of cylinders with at least one inlet valve and at least one exhaust valve per cylinder having a first camshaft for the inlet valve controlling the opening of the inlet valve, a second camshaft for the inlet valve controlling the closing time of the inlet valve, and a camshaft phasing mechanism coupled to the second camshaft overcomes drawbacks with prior art systems.

[0009] An advantage of the present invention is that it provides an inexpensive, compact system for changing the compression ratio which does not harm operation of the engine.

[0010]

By controlling the closing of the inlet valves (IVC) of all the cylinders of a cylinder bank by a dedicated, second camshaft which is provided with a phase shifter, it is possible to set a delay in the closing of the inlet valves. A delay of this type reduces the effective compression ratio when the diesel engine is operating, This provides an advantage when the engine is warmed up to reduce the production of noise and the

emissions of pollutants. At the same time, the first camshaft, which is separate from the second camshaft, ensures that the opening of the inlet valves can take place independently of the closing. Therefore, there is no disadvantageous change in the opening of the inlet valves associated with a delay in the closing of the inlet valves. Furthermore, the proposed diesel engine has a relatively simple structure, since it is based on inexpensive, compact mechanical components.

[0011] The phase-shifting mechanism of the second camshaft is preferably designed to delay the closing time by up to 60 ° after the usual inlet closing (IVC). A delay of this extent is sufficient for the desired range in compression ratio and can still be achieved relatively successfully mechanically. An example of a mechanism of this type has been described by Steffens (Steffens N. et al. (1977) Kontinuierliche Ein- und Ausla ß nockenwellenverstellung f ü r Klein- und Gro ß serie [continuous inlet and exhaust camshaft adjustment for small and large series], 6. Aachener Koll. Fahrzeug- und Motorentechnik, 1005-1024).

[0012] According to a preferred configuration, the first and second camshafts are arranged parallel and closely adjacent to one another. In this way, it is possible to ensure that both camshafts are able to act on the same inlet valves and take up relatively little space.

[0013] The drives which effect rotation of the first and second camshafts are preferably arranged at opposite ends of the camshafts, i.e., the drive for the first camshaft is arranged at a first end of this camshaft and the drive of the second camshaft, which is parallel to the first, is arranged at the opposite end of the second camshaft from said first end of the first camshaft. An arrangement of this type makes optimal use of the space available at both ends of the camshafts.

[0014] According to a refinement, the diesel engine includes a turbocharger for boosting the pressure of the air introduced into the cylinder. The engine also has an engine timing unit, which is coupled to the phase-shifting mechanism of the second camshaft. The engine timing unit adapts the delay in closing of the inlet valves as a function of the engine speed, the engine torque and/or the charging pressure of the turbocharger. In particular, the delay in closing of the inlet valves is reduced to a greater extent as engine torque increases at a low engine speed. Reducing the

compression ratio, by delaying the closing of the inlet valves, has the additional effect of reducing the engine torque, since the volume which is present in the cylinder when the inlet valves are closed is reduced.

[0015] In the case of a diesel engine with a turbocharger, at relatively high engine speeds, at which the turbocharger is completely active, the effect of the reduced chamber volume is compensated for by higher charging pressure when the inlet valves are closing. However, this compensation does not function at lower engine speeds, at which the turbocharger does not produce a sufficient charging pressure. According to the proposed configuration of the engine timing unit, this undesirable drop in engine torque is combatted by adjusting the delay in the closing of the inlet valve being continuously varied as a function of the engine speed, the engine torque and/or the charging pressure of the turbocharger. In this case, at low engine speeds and low engine torques, IVC is delayed to produce quiet combustion with low emissions. On the other hand, at low speeds and full torque, IVC is delayed to a lesser extent to maximize the volumetric efficiency and the torque. At full torque and higher engine speeds, the turbocharger is increasingly able to generate higher charging pressure, so that IVC can correspondingly be delayed in steps to reduce the mechanical loads and the production of noise.

[0016] In a special configuration of the diesel engine, the first camshaft, which controls the opening of the inlet valves, may simultaneously be coupled to the exhaust valves, to control the opening and/or closing of the latter. This additionally simplifies the structure of the diesel engine, since there is no need for a separate camshaft for the exhaust valves.

[0017]

Furthermore, the invention relates to a method for controlling a diesel engine having a turbocharger, in which to vary the compression ratio the closing of at least one inlet valve is delayed. The method is distinguished by the fact that at a low engine speed the closing of the inlet valves is delayed to a lesser extent as the engine load increases to ensure a constant engine output. This method, in the manner which has been explained above, takes into account the fact that, at low engine speeds, the turbocharger can compensate for the drop in torque by a delayed IVC rather than by an increased charging pressure. Thus, if a higher engine output is demanded, the

delay in IVC is reduced accordingly.

## Brief Description of Drawings

[0018] The invention is explained in more detail below, by way of example, with reference to the drawings, in which:

[0019] Figure 1 diagrammatically depicts the arrangement of two camshafts in a diesel engine according to the invention with a common camshaft for inlet and exhaust valves;

[0020] Figure2 diagrammatically depicts the arrangement of three camshafts in a diesel engine according to the invention with different camshafts for inlet and exhaust valves; and

[0021] Figure 3 shows a time diagram illustrating the variable closing of the inlet valves in a diesel engine according to an aspect of the invention.

## Detailed Description

[0022] Figure 1 diagrammatically depicts a plan view of two camshafts 1 and 2 which are assigned to a cylinder bank of a diesel engine (not shown in more detail). A diesel engine is, in this example, characterized by a high compression ratio (typically 18:1 compared to 10:1 for spark-ignition engines), late injection of fuel in the compression stroke, a stratified air/fuel mix in the cylinder, and compression ignition. At its upper end in the figure, the first camshaft 1 has a gearwheel 3 or the like which can be driven by a chain, a belt or further gearwheels. On camshaft 1, there are cams (not shown) which interact with the inlet valves and the exhaust valves of the cylinder bank of the diesel engine.

[0023] In conventional diesel engines with a camshaft for the inlet and exhaust valves, both the opening and the closing of the inlet valves and of the exhaust valves are closed by one camshaft. According to the invention, however, a second camshaft 2 is arranged parallel and closely adjacent to first camshaft 1. This second camshaft 2 exclusively controls closing time of the inlet valves (IVC). Accordingly, the first camshaft 1 then controls opening of the inlet valves (IVO) and opening (EVO) and closing (EVC) of the exhaust valves.

[0024] The second camshaft 2 is driven at its lower end, as shown in figure 1, so that its drive lies opposite that of the first camshaft 1. Furthermore, a phase-shift device, 4 which allows a variable phase shift of the second camshaft 2 by up to a crankshaft angle of 60 ° , is provided between the second camshaft 2 and its drive. One way of controlling the opening and closing of a valve by two different camshafts, whose phases can be shifted relative to one another, is disclosed, for example, in U.S. Patent 5,592,906, to which reference is expressly made. Other configurations can be found in GB 170 855, U.S. 5,178,105 and EP 0 472 430 B1.

[0025] Figure 2 diagrammatically depicts a plan view of an alternative configuration of the camshafts of a diesel engine. The starting point in this case is prior art in which two different camshafts 11 and 15 are provided for the inlet valves and the exhaust valves of a cylinder bank. Camshaft 1 controls exclusively the opening (EVO) and closing (EVC) of the exhaust valves. Unlike in the prior art, however, the first camshaft 11 controls only the opening of the inlet valves (IVO), while, in a similar manner to that shown in Figure 1, a second camshaft 12 is provided parallel and closely adjacent to the first camshaft 11, for the purpose of closing the inlet valves (IVC). The coupling and control with a phase-shift device 14 is similar to that shown in Figure 1, and consequently does not need to be described again.

[0026] Figure 3 shows a diagram presenting the possibilities for valve control in a diesel engine according to the invention. Time is plotted on the horizontal axis, with each of the points at which the piston is at the top dead center (TDC) being marked. The opening stroke of the exhaust valves and inlet valves is plotted on the vertical axis. Curve 20 describes the opening behavior of the exhaust valve, while the set of curves 21 belongs to an inlet valve. From the illustration, the opening time of the exhaust valve (EVO), of closing of the exhaust valve (EVC) and opening of the inlet valve (IVO) are unchanged, the two latter times lying just after and just before top dead center (TDC), respectively.

[0027] Closing time of the inlet valve can be varied, within a predefined range Δ of typically 60 ° , after bottom dead center with the aid of the phase-shifters 4, 14, which have been explained above, on camshafts 2 and 12.

[0028] Varying closing time of the inlet valves in this way leads to a corresponding

change in the effective compression ratio, which can therefore be optimally matched to the operating conditions (engine cold start; engine which has warmed up, etc.). In this way, it is possible to minimize the production of noise and the emissions of pollutants from the diesel engine. All the key parameters EVO, EVC and IVO advantageously remain unchanged for the timing control of the inlet and exhaust valves, so that there are no disadvantageous side effects on engine operation.

[0029] I claim: